TIME TRAVEL AND THEORIES OF TIME

The intuitive outlook of the world is seriously threatened by many advances in modern sciences. The situation was quite different one hundred years ago. The common-sense view of the world was not at odds with the scientific theory until the last decades of the nineteenth century. Mechanics and phenomenological thermodynamics were almost intuitive in Western thought. After the first developments of statistical thermodynamics and electromagnetism and especially following the discovery of General Theory of Relativity (GTR) and Quantum Mechanics (QM) a disagreement arose between our intuitions about the structure of the world and the scientific descriptions of it. The existence of new scientific models questioned our ability to understand reality and our comprehension of understanding reality. But which one is the most correct: our everyday intuitions which are relatively stable and almost universally endorsed or scientific explanations of the world which are continually changing? From the beginning QM and GTR were beset by problems of their foundations so that there are many interpretations of them. The situation did not change too much in the meantime: QM raises problems of measurement and non-locality and GTR the problem of spacetime singularities and acausality, which are mainly due to the fracture between common sense thought and scientific models.[1] This should be one of the most important tasks of philosophy today: to explain and to analyse the concurrence and the divergence between our intuitions and scientific models.

But there are some *Gedankenexperimente* that trouble our minds and equally the sciences. They can be considered as belonging to a third place apart from everyday intuitions and scientific explanations, a „no man's land". Initially both everyday thinking and scientific outlook rejected, although with completely different arguments, such fancy devices as the products of mere imagination. One of these is so-called time travel or, in the scientific language of GTR, closed timelike curves (CTC). The two concepts are connected and the border line between them is vague. The phrase „time travel" comes from science fiction, but in fact philosophical and logical ideas are involved. The concept of CTC was used in connection with Gödel's solutions to Einstein's field equations (EFE) for a particular configuration of matter distribution in the universe. While CTC is a very technical term used only by a few scientists, the more intuitive idea of time travel is ubiquitous in literature, movies and TV series. Although few people grasp the meaning of CTC actualisation in our universe, anyone understands that if time travel were possible, all our models of physical reality, biological evolution, human history and life in the universe would be radically revised. Common thinking and scientific theory acknowledge that if we are to accept time travel or CTC (in our Universe) the grounds of our knowledge must be somehow revised and concepts as „infinity", „law of nature", „evolution", „knowledge", etc. should be reshaped.

Like QM and GTR, discussions of time travel and CTC are a contested territory for science, philosophy and common-sense thinking. We will follow in this paper some of the arguments of philosophers and scientists and we will discuss some notions used in the discussion. All these are in themselves already committed to a peculiar metaphysics of time that shall be revealed gradually.

[1] [Earman, 1995a, p. 4].

So this puzzle can be approached in two different ways. Time travel can be described without using the formalisms of modern physics, but just a minimal logical apparatus and philosophical speculations regarding identity in time, nature of time, temporal parts, existence and becoming. It is well described in certain terms of semantics and analytical ontology. Analytical philosophy argues that the problems of time travel can be solved in a conceptual and linguistic frame using only the informal arguments of philosophy. Some philosophers don't employ GTR formalisation because it's too counter-intuitive and somehow relative to a system of presuppositions[2] or grammar[3] and they think that philosophical argument itself is enough to illuminate or even settle this question.

For philosophers of science and scientists this speculative approach to time travel is derided as „armchair philosophical reflections".[4] They use topology and GTR to define spacetime singularities and CTC. In John Earman's words, scientists require time travel (a) to be compatible with the laws of physics, (b) to not imply backward causation and (c) to not be open to a rereading on which no time travel takes place. Science is not primarily concerned with logical contradictions, as (a) would secure this; neither with the counter-intuitive aspects of time travel, as relativity is at odd with our common ideas of „space" and „time" so nobody expects an intuitive idea of time travel.[5] The main problem for the scientific approach to time travel is to maintain the laws of physics, and these demands will solve the problems like autoinfanticide and other logical paradoxes. A scientific discussion on CTC should begin not with fiction and counterfactual conjectures, but with the solutions to Einstein's Field Equation (EFE).[6]

In the last fifty years there were many interpretations to so-called time travel coming from both directions. Each approach hopes to solve the problem with independent tools: philosophy suggests that only the logical and conceptual constraints should limit and should determine the possibility of time travel while the scientific approach compels the time travel to those models that are compatible with the laws of nature. The differences are so important that in John Earman's opinion there are different types of time travel.[7]

The first two sections will outline two types of time travel, mainly distinguished by these the approaching methods: the philosophical and the scientific one. Sections 3), 4) and 5) will present the arguments for and against the possibility and the probability of time travel. In section 6) we will describe two theories of time currently on debate and in section 7) we will try to show that time travel is a serious challenge for both of them and an improvement is necessary.

[2] For Putnam, necessary truths are relative to a body of knowledge. He takes time travel as an example. So that the alleged logical impossibilities are due to our normal use of language and of terms like „existing" in time and space, „travelling" along world-lines, etc. If we start to speak on time travel things go wrong in countless ways. But we can freely choose a mathematical description of the phenomena. The problem of time travel isn't a mathematical or a logical one, the problem relies on the option for one system of terms or an other, on our conceptual schema [Putnam, 1962, 665-669]. Weingard criticised Putnam for applying only accidentally some methods of STR in his account of time travel, without solving the problem of integrating time travel into a physical theory. [Weingard, 1972, 118].

[3] #Rom Harre#

[4] [Earman, 1995a, p. 194].

[5] [Earman, 1995a, 125].

[6] In *Albert Einstein: Philosopher-Scientist*, ed. by M. Schilpp, 1949.

[7] [Earman, 1995a, p. 163].

1) Wellsian time travel

The term first appeared in the novel *The Time Machine* by H. G. Wells (1898). It was discussed in the analytical philosophy and logic of the last forty years and mainly rejected because it implies such strange oddities as materialisation and dematerialisation, as well as ubiquity and backward causation, but not necessarly the violation of energy conservation or other laws of physics. The simplest scheme of this time travel presupposes that we have an object M (typically the time machine and its occupant) that can appear *ex nihilo* and can disappear *ad nihilum*. The evolution of M can be represented on a section of 4-D manifold (x,y,z,t) in which space is confined to a single variable. To understand better the time travel argument, it's useful to bring to light the difference between time (t) inside M and time (T) outside it, namely the difference between private time (internal time) and public time (external time).[8]

There are at least three types of time travel in the wellsian meaning, depending on when and where appears the fracture in the spacetime evolution of time machine. The vertical axis is time, the horizontal one is space or a transformation of spatial ordinates blended together in a single variable (see Fig. 1).

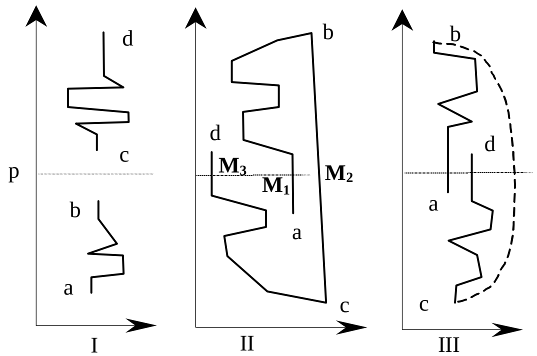

Figure 1

I) In the first case M disappears at b and reappears at c, having a normal evolution on a-b and c-d intervals, but with a jump from b to c because between b and c it doesn't exist at all. This can be interpreted as a „gap" in the existence of the machine. In this gap of existence we can say that $\Delta S_M = 0$ (entropy variation between two states of M)[9] and also $\Delta t=0$.

II) In the second case M traverses the period b-c without disappearing. From the outside, all the processes in M are going backward in time. While inside of M nothing strange happens, the outside world seen from inside is going backward in time. The main feature and the most embarrassing is the decreasing entropy in M. If the filmed picture of M is played backward then the events in it are all normal. This is a reason

8 [Lewis, 1986b, 69]. It can be proved that difference between public and proper time can restore the consistency of time travel, but cannot solve the problem of simultaneity [Faye, 1989, 234]. This is as an import from the Theory of Relativity, but not an essential one, as the difference between times and spaces of systems of references was known before Newton.

9 It's worth noting again that the use of entropy does not bestow a theoretical flavour to this approach and it is somehow counterfeit.

for supposing that time inside the machine in going backward only if we admit further metaphysical assumption: that the direction of time is determined by the direction of increasing entropy, although this is an hypothesis that can be refuted or qualified and it holds only in a certain view of time that infers the direction of time from the entropy. As we can consider the time machine an isolated system, locally we should expect an increase in entropy, but this is not the case. In this situation, from $\Delta S_M \bullet \Delta S_{universe} < 0$ (the entropy inside M flows in other direction that the entropy of the Universe) we can infer $\Delta t \bullet \Delta T < 0$ (e.g. the two times are flowing in different directions). The internal time on b-c is backward oriented from future to past. There is an argument against this inference proposed by Weingard when he criticises the example given by Putnam based on the entropy arrow of time.[10]

III) In the third situation M passes into non-existence between b and c, but it reappears in past, before b. Here we have a combination of I) and II). The entropy of M between b and c is null, so M is beyond spacetime of the Universe. The time t doesn't flow in M; so as $\Delta S_M = 0$, therefore $\Delta t=0$ or t doesn't have any sense.

It is possible to have a fourth situation in which M is evolving very slowly in time, as in STR and after M is sent off in a very remote area of the universe with a relativistic speed it returns back and its internal clock will be slowed down. But this situation is not at all a time travel, as time travel presuppose a move *back* in time not only a move forward in time at a different „speed" such a pass over the normal flux of time.[11]

The ontological status of M at the moment p is very uncommon in all three situations. If we accept the classical criterion for existence, in the first and third situation M doesn't exist at all, as it doesn't occupies a spatiotemporal place. In the second situation we have *three* M's, the first (M_1) is a physical object evolving normally in space and time from *a* toward *b*; the second one (M_2) is moving backward from *b* toward *c* in time and its entropy is decreasing; the third (M_3) is a normally object evolving from *c* toward *d*. The internal clock on M_2 will show a time before the time displayed on M_1 and after the time of M_3, although the external clock shows only the time of M_1. Backward causation can occur at p anywhere, as M_2 and M_3 are continuants of M_1, but if M_1 is in the light-cone of M_3 (consider the horizontal ordinate not at a cosmic magnitude) then it can be influenced by some events in M_3, as M_3 should be influenced eventually by some events in M_1. In the third situation we have almost the same situation, but M_2 doesn't exist, so the backward causation is possible between M_3 and M_1.[12] Reversals of causation are normal in this arrangement, as they are necessarily involved in time travel.

2) Gödelian time travel

Time travel is closely linked to Einstein Field Equations (EFE), the ground of GTR. Surprisingly enough, some solutions to EFE which had been given before 1949 supported in some conditions time travel but nobody noticed it[13] as the problem of CTC was overshadowed by the discussions on spacetime singularities. Einstein

10 [Weingard, 1972, 126-129] and Huw Price, *Time's Arrow & Archimedes' Point: New Directions for the Physics of Time*, New York Oxford, Oxford University Press, 1996.

11 The above discussion can be found in [Macbeath, 1982, 399].

12 Weinland attempted to integrate the situation II within the laws of physics by assuming that we can have an antimatter M_2 [Weingard, 1972, 122], so in b the machine annihilates himself. This assumption was previously rejected by Putnam.

13 The solution of Van Stockum (1937) of a infinite rotating cylinder of dust, reanalysed by Tipler in 1974 for the finite case contains CTC.

himself had a strange attitude regarding the singularities in EFE and he never accepted them totally.[14] In 1949 the first solutions to EFE permitting CTC were provided by Gödel. Concerning CTC, Einstein suggested that they can be further analysed and he didn't reject them.[15] Einstein asked himself if such cosmological solutions allowing time travel „are not to be excluded on physical grounds". That was the beginning of the scientific approach to time travel via the analysis of universes accepting CTC. Chandrasekhar and Wright had questioned them in a paper in 1953[16] and after that the problem was treated implicitly as a sneaky physical dilemma in GTR. The classical textbooks on General Relativity till '90's scarcely mention CTC and avoid any discussion on it.

Gödel introduces a transformation of Minkowski linear coordinates to cylindrical coordinates.[17] By this transformation the time becomes circular and the world is recursive as we haven't a single time slice in this universe and we cannot speak of this universe at a single time and as a consequence an object has no temporal parts in this Gödelian universe, and the structure of time is „closed". A spacetime manifold that include non global CTCs cannot be globally foliated, i.e. sliced in spacelike surfaces that can be regarded as successive nows.[18]

We can define a condition for the existence of CTC by a topological condition on the light cone. A timelike close curve[19] doesn't exist in a Minkowski spacetime. We define $p \ll q$ as a relation connecting two points if there is a non-trivial timelike future-directed curve from p to q, which means that p can be causally connected with q. The sets $I^+(p)=\{x|p \ll x\}$ and $I^-(p)=\{y|y \ll p\}$ are the *future-set* respectively the *past-set* of the point p. There exists a CTC crossing p if $p \in I^+(p)$. The most important feature of CTC is that they are continuous and we can preserve the criterion of individuality. On a CTC there are not dematerialisation or materialisation as in Wellsian time travel. In a Gödel universe each point contains at least one CTC.

Gödel transformations can be rejected on various basis, but the problem is that CTC can appear in a variety of matter distributions described by classical GTR where matter distorts the geodesics so strongly that CTC could occur. For this reason the scientists are divided. First are those who impose a chronology condition („there is no CTC in the time-oriented spacetime") in the Penrose-Hawking theorems regarding singularities (the most important result in GTR) and believe that GTR has the resources to show that chronology violations have to be kept (some reason should be that if CTC were not present from the beginning they would not occur later and a initial state with CTC was not reasonable). Second, there are those who take seriously

[14] P. Bergmann in H. Woolf (ed.), *Some Strangeness in the Proportion*, MA, Addison Wesley, 1980, p. 156. He believed till the end of his life that Unified Theory will arise no singularities. He pronounced this possibility repugnant to his physical intuition: „Dies widerstrebt meinem physikalishen Gefühl aufs lebthaftteste", in [Earman, 1995a, 26].

[15] But as Earman proves the CTC and singularities are not separate problems [Earman, 1995a].

[16] The aversion to CTC was removed by Howard Stein in [Stein, 1970].

[17] K. Gödel „An example of a New Type of Cosmological Solutions to Einstein's Field Equations of Gravitation", Reviews of Modern Physics, vol. 21, nr. 3, July 1949, 447-450 reprinted in Albert Einstein: Philosopher-Scientist, ed. by P. A. Schilpp, 1949.

[18] [King, 1999, 276n7].

[19] Given a Minkowski spacetime, a line element is $ds^2 = dt^2 - dx^2 - dy^2 - dz^2$ and in a general tensorial form: $ds^2 = \eta_{ab}\, dx^a\, dx^b$. Unlike the Newtonian space, the line element can be negative also or null. A curve between two points having a positive length is a timelike curve if its length (by integration of the line elements) is positive, a spacelike if its length is negative and a null curve or a light curve if its length is zero. The light cone is a double cone formed by all the null curves (straight lines here) passing by the origin. All timelike curves are inside the cone and the spacelike ones outside it.

the violation of chronology condition, some of the most firm being K. Thorne, J. Friedman, I. Novikov.

3) Arguing against wellsian time travel

Why was time travel rejected by philosophers? It is clear that the story of a machine going forward and backward in time put in jeopardy some of our classical views of reality because it infringes our idea that there is a fundamental „distinctness" between past and future. But a question raises: is time travel nothing but a thought experiment or a subject of science-fiction? I think that it is also a challenge to our system of representing time and space and it can be used as a tool to inspect and verify our models of reality and that the analysis of time travel improves our understanding of the spacetime structure of the universe.

Firstly, time travel is against our intuition of time as a single line without any break or branching point. We're very familiar with the isomorphism between time order and real number set. We cannot accept that a number should be greater and in the same time smaller than another one. In this respect it is very appropriate to quote Swinburne' argument against time travel: „If the present instant t_1 will return then the next instant subsequent to this one, t_2, will be both before and after t_1".[20] This seems to be a logical argument against *all* types of time travel, Gödelian or Wellsian as well. Or, in other words „a certain event corresponding to a single point in which the corresponding world line recrosses itself would be simultaneous with a remote future instants."[21] So if $t_1 < t_2 < t_1$ is an impossibility, then time travel is impossible. L. Dwyer tried to reject Swinburne's assumption on the basis that it presuppose that t_1 occurs twice and this is a fault similar of postulating a hypertime, although this is not necessarily true.[22]

Secondly, time travel is against our common-sense belief that a thing is occupying a single place at a moment and it cannot be in two place at the same time. This a problem concerning identity of objects in space and time. At the moment p in the second situation described in Figure 1 we have three objects numerically identical. As J. Faye argues against time travel, our concept of an object involves it havimg a spatially finite and bounded extension. If a thing is separated from another and there is no connection between them, then they are *eo ipso* different objects. The spatial boundedness makes them countable and numerically different.[23] In Faye' opinion, to maintain the *uniformity* of laws governing the perceptual access to the world around the traveller and his younger replica (the person he should have meet in the past) is impossible, so we cannot retain the relation of simultaneity of time traveller.[24] So this should be an argument against time travel based on identity and simultaneity.

Thirdly, time travel involves changing the past. From this derives the grandfather paradox and auto-infanticide discussed by Lewis. This is considered by some philosophers the major hindrance to accept time travel. Backward causation *can* occur if we accept that the past can be changed. In his causal theory of time, Reichenbach uses as axioms that „the past never comes back" and „we cannot change the past, but

[20] R. Swinburne, *Space and Time*, Macmillan, 1968, p. 169.

[21] M. Capek, „Time in Relativity Theory: Arguments for a Philosophy of Becoming" in J. T. Fraser (ed.) *The Voices of Time*, G. Brazziler, NY, 1966, 448.

[22] [Dwyer, 1975, 347].

[23] [Faye, 1989, 230].

[24] [Faye, 1989, 234].

we can change the future".[25] This helps him to define time in terms of causality. If the past would came back, we should have a closed causal chain. The same situation would be if the past would be changed. The causal chain does not merely happen to be missing, „but is *physically* impossible".[26] But Reichenbach doesn't reject the self-encounter of a younger ego, a situation paradoxical to us from a physical point of view, but not *logically* impossible. In a situation with a self-encounter ego, there will be no time order in the usual sense.[27] In the same manner, Stephen Hawking and George Ellis tried to prove on a logical basis that time travel is impossible.[28] The method used by the two cosmologists is *reductio-ad-absurdum*. The four premises used are: 1. A time traveller exists prior to carrying out the time travel. 2. All physical objects have continuous existences. 3. Time travel to the past is logically possible. 4. Travelling „backwards" in time would enable a time traveller to stop him/herself from embarking to his/her time journey. The only premise that can be false is the third one.

As Smart remarked[29] we can accept or reject time travel merely on a semantical ground by making conceptual analysis of time and space. Space has two meanings: space is a *continuant*, it is like an object, it has some properties as „being occupied by X" or „being curved". The main feature of it is that it can change or stay the same. In the second sense space is described mathematically and it is tenseless and it is not a continuant. So, the Minkowski theory of space-time engaged this sense of space. We are speaking about time travel in the continuant sense of space. A travel in space-time of an object O from point A to point B means that the worldlines of O intersects the world lines of A and B. In this representation, as Schlick remarked, „time is already represented within the model and cannot be introduced again from outside".[30] So, in a pure four-dimensional language of world-lines the motion in an ordinary way of changing time and space ordinates doesn't exist. We cannot speak of travelling in time and in space and we cannot represent motion in four-dimensional space-time. The possibility or the impossibility of time travel resides in the meaning given to this concept, like in Putnam's interpretation. In discussing his argument, Smart shows that we can interpret a relativistic journey as time travel to the future, as I can shot myself from earth to a very remote part of the universe and when I come back I will find my contemporaries very old, as to say they were futurised in the meantime. This is a well-known consequence of The Special Theory of Relativity. Smart accepts the conceptual possibility of time travel if we define properly time, space and motion, but he cannot accept time travel as moving in a four-dimensional spacetime.

4) Arguing for and against CTC

A good example of how time travel can be rejected using not pure logical speculation, but instead EFE and details about the structure of spacetime is the well-known conjecture against time travel, a standard formulation of which was given by Stephen Hawking, namely the *Chronology Protection Conjecture* (CPC).[31] This is a principle requiring that the *laws of physics prevent the appearance of CTC* and generally it is thought as being *ad-hoc*. Hawking used it against time travel. He denied

25 *Direction of Time*, University of California Press, 1956, p. 22-24.
26 Idem, p. 39.
27 Ibidem, p. 37.
28 [Hawking & Ellis, 1973, 189].
29 „Spatialising Time", *Mind*, 64 (1955), pp. 239-241.
30 M. Schlick, *Philosophy of Nature*, New York, Philosophical Library, 1949, p. 43.
31 [Hawking, 1992].

we should resolve the paradox just by conjecturing that in a universe where CTC are possible there are some changes in the free will of the time traveller. But „this will not be necessary if what I call the chronology protection conjecture is correct".

As Kim and Thorne had previously shown[32], a sort of time machine can be conceived using a non-trivial topology involving wormholes. Hawking proves that in order to create a wormhole one has to distort the metric so much that closed timelike curves appear. The mathematical result of Hawking is that „If there is a timelike tube T connecting surfaces S and S' of different topology, then the region M_T contains closed timelike curves."[33] (here S and S' are spacelike surface without boundaries, S' being the result of warping the surface developing from S and having a different topology, saying with a wormhole or a handle, and M_T is region of spacetime bounded by T, S and S'). But how this can be prevented? There is a constant (B) which depends on the quantum state and spin of the field. If B is negative the energy-momentum tensor will have a repulsive gravitational effect in the equation for the rate of change of the volume. „This will tend to prevent the spacetime from developing a Cauchy horizon. If B is negative spacetime will resist being warped so that closed timelike curves appear. If B is positive, „the gravitational effect would be attractive, and the spacetime would develop a singularity, which would prevent one reaching a region of closed timelike curves". Either way, with B having all possible values, Hawking considers that there are theoretical reasons to believe CPC by the fact that laws of physics prevent the appearance of CTC. The experimental evidence is that „we have not been invaded by hordes of tourists from the future".[34]

But Hawking's argument against CTC is not very convincing, as J. Earman recently argued. He thinks that time travel is possible but a time machine cannot be operated. A time machine in a weak sense does not produce a CTC but reveals it. A time machine in a strong sense brings about a CTC.[35] The chronology protection theorem (CPT) is one of the most important results connected with GTR: the idea is to analyse very carefully the time machine (in a strong sense) and to prove that if we accept it we have to run afoul of some plausible *physical* constraints. CPT tries to reach impossible results starting from the acceptance of time machines. It is like a *reductio ad absurdum*.

Earman proved that we haven't yet a strong argument to undermine the possibility of a „strong" time machine. We will not enter here into technical aspects of CPT, but we have to mention Earman's idea of constructing a CTC on a hypersurface Σ without edge such that there is no CTC in the $J^-(\Sigma)$ (the causal past of Σ). Then he discusses two CPTs, Hawking's and Tipler's, all settled within classical GTR. However CPTs do not suffice to reject time machines in a strong sense but merely make them very difficult to operate.

The last discussions in Earman' paper are very interesting, as he speculates about Quantum Field Theory (QFT). On one hand QFT can help time machine by countenancing matter that violates the weak energy condition. On the other hand there are at least three ways in which QFT militates against time travel and we can expect that QFT will wreck the dream of operating a time machine, but we haven't yet a viable QFT. In this situation none of the CPT in the frame of classical GTR can offer

32 [Kim & Thorne, 1991, 3929].
33 [Hawking, 1992, 609].
34 [Hawking, 1992, 610].
35 [Earman, 1995b, 126].

an argument strong enough to reject time travel. We have to wait for a QFT to ensure the best version of cosmic censorship.[36] To conclude, dismissing CTC out of hand is a practice which reminds us of the dogmatism about singularities in GTR prior to the singularity theorems or worse, about dogmatism against STR or QM before their first experimental confirmations.

5) Between being improbable and being impossible

The best known argument for accepting time travel not as logically impossible, but merely an oddity for our intuition, is due to David Lewis. A possible world in which time travel took place would have be a strange one: this puzzle comes from the paradox of changing the past. The time traveller cannot change his past. P. Riggs calls this argument „the Principal Paradox of Time Travel". He gives ten assumptions of Lewis' argument:[37] (i) Time is only one-dimensional (although Lewis does not reject two dimensional time). (ii) Propositions about past events are either tenselessly true or tenselessly false. (iii) The occurrence of any contradictory circumstance is impossible. (iv) Human beings do have (at least) limited freedom of action. (v) Events could have been otherwise than what they are, have, or will be. (vi) Tim is not created *ex-nihilo* (in Lewis argument, Tim is a time traveller who goes back fifty years to kill his own grandfather) (vii) Tim is a normal, adult human being whose bodily functions, reflexes, memory, etc., are not impaired in any way by his travelling in time. (viii) Tim's intent and determination to kill his grandfather is unaffected by his travelling in time; (ix) Tim actually shoots at his natural grandfather and not a person he mistakenly believes to be his natural grandfather; (x) Tim does not „pass into" another universe inhabited by similar individuals to those in his universe.[38] Lewis argues that you cannot change your past because if something can happen than its happening is compossible with certain facts. Tom can kill his Grandfather, but his killing Grandfather is not compossible with a more inclusive set of facts, especially what Grandfather was doing after Tim's return in past.[39] Tim wants to kill his Grandfather and can do it. But as he tries to kill him, appears a set of circumstances disallowing his desire. This failure is not due to any lack of capacities of Tim, or of an opportunity. Lewis states the „obvious, but readily overlooked explanation, that people often fail to reach goals that usually are well within their ability to achieve."[40]

Horwich has another explanation for time travel. He diverges the discussion about time travel from possibility to probability and he asks himself about the real probability and epistemological possibility of time travel. The closed causal chains are double causal relations in which c causes e and e causes c^*. We can imagine the situation in which c and c^* are mutually exclusive. Closed causal chains can produce bilking arguments, e. g. the hypothesis that in a closed causal loop the initial environment can be precluded, in other words c^* can be lastly the non-existence of c. Theories implying bilking arguments are: theoretical spacetime of Gödel, Feynman's

[36] [Earman, 1995b, 137].
[37] [Riggs, 1997, 50].
[38] It worth noting the different classes of assumptions we have here. The first is a topological claim concerning the very nature of time. There are some theories of bidimensional time but we'll not discuss them here. The second one is about the truth structure of proposition about past and future and it has a semantical commitment. The third and the fifth are logical assumptions, while the forth concerns the free will of human beings. The last assumptions are descriptions of facts.
[39] [Lewis, 1986a, 79].
[40] [Riggs, 1997, 51].

idea that positrons are nothing but electrons moving backward in time and the perfect precognition.[41]

Horwich proves that time travel is not impossible but highly improbable and he discusses time travel in Gödelian sense. The occurrence of such circumstances as the auto-infanticide, etc. will failure and such circumstances are ruled out by what we know about the world. The conclusion is that closed causal chains deriving from Gödelian time travel are *epistemologically* impossible.[42] Gödel himself showed that such structures of space time permitting time travel are technologically impossible because the energy required would amount to the mass of several galaxies.

Concerning Feynman' theory, Horwich asks how can we admit that a positron can be an electron moving backward in time? Let's mention shortly Berger's argument for the Feynman interpretation.[43] He starts with an algorithm using an input-output quantum machine.[44] In conformity with Feynman, electrons never travel back in time. A re-entrant trajectory for a particle means that the input of the quantum machine is before the output, with $\Delta t<0$. Bohr showed that in QM we have to deal only with non-re-entrant particles.

We can adopt another microphysical theory in which we have no antiparticles (we have no positrons as well) and every statement on generation of particles-antiparticles pairs must be translated into statements about re-entrant particles. We translate all statements about anti-particles into statements about re-entrant particles. This will imply some changes in the meaning of „time". But we have not to confuse the direction of time with the concept of re-entrance. This is a new concept of Feynman physics. In pre-Feynman physics, particles could undergo re-entrance, but they did not do so. In the Feynman model, re-entrance is an axiom, as the velocity of light is postulated in Special Theory of Relativity. It can be put like this: in physics there is no law which permits re-entrance in any but a fully conventionalistic manner. But the acceptance of both entrance and re-entrance will not mean a change of the meaning of fundamental concepts, but rather the discovery of a new class of physical processes. Re-entrance should not be decided by the conceptual analysis, but by physics.

In Horwich's opinion, the empirical bilking argument does not suggest that Feynmam's model is epistemologically impossible. His conclusion is that closed causal chains cannot be dismissed on *a priori* semantical grounds, nor by an *a posteriori* bilking argument, so although the bilking argument isn't an universal tool for rejecting closed causal chains, it can discard time travel as highly improbable.

Horwich also defends Gödel's claim that time travel could occur. He dismisses the situation of a wellsian travel in time as „there is no physical theory to give it credence and more difficult, since extra problems to do with personal identity are involved."[45] He considers four alleged paradoxes of time travel. 1) In gödelian time travel, M traverses some temporal interval in a time having a different length than the duration of that interval. This paradox is solved if we accept different frames of references for time allowed by standard STR.[46] 2) There is an incompatibility with

[41] Horwich in [Savitt, 1995, 261].
[42] Horwich in [Savitt, 1995, 264].
[43] [Berger, 1968].
[44] R. Feynman, *Theory of Fundamental Processes*, NY, Benjamin, 1962.
[45] [Horwich, 1987, 112], an improved version of „On Some Alleged Paradoxes of Time Travel", *Journal of Philosophy*, 1972, 432-444.
[46] This was used by D. C. Williams to prove the fault of Wells' time travel. „The Myth of Passage" in *Journal of Philosophy*, 48, pp. 457-472.

Leibniz's law that the identical object have all the same properties. This alleged paradox is ruled out by a language which is time indexical relatively to proper time and not to general time. 3) The third paradox regards the changing of the past, and here Horwich insists on the difference between changing the past and influencing it. The former is indeed impossible, as it is possible with respect to the future. The latter, however, involves no such contradictions, and this is what is required for time travel. But Horwich didn't explicitly define how we can „influence the past". 4) The fourth argument concerns autoinfanticide, very similar to Lewis' one. We are again in the situation pictured by Lewis, except that Horwich is discussing directly the autoinfanticide. This is refuted by the restrictions imposed on the class of causal chains. The idea is to accept that there are constraints on timelike curves that may act as loci for particular sorts of causal chain. Closed causal chains are subject to consistency conditions.[47]

The next move is to accept that bilking arguments involve implausible coincidences. We can trust that something prevents the bilking and this should be either the structure of spacetime, or the fact that the individuals who organise trips into past are not concerned with bilking, either the fact that to close a timelike curve should need a too great amount of fuel (Gödel's own explanation), or that quantum fluctuations should prevent it.[48] We can add other reasons to reject time travel. One of them is the practical impossibility of intentional bilking strategies. Horwich's conclusion is that a distribution of circumstances allowing time travel is highly implausible. Even if we are living in a universe like Gödel's, it is necessary for the initial state of a universe with closed timelike lines to possess a certain order. These special conditions have to conform with a Gödelian spacetime and engender the entropic behaviour we observe. This should be a small subset of all possible initial conditions compatible with our entropic data. We cannot conclude that there are no closed timelike curves. On Horwich's view, we cannot prove that we are living in a cylindrical spacetime, but this should be highly improbable.

6) Two theories of time

As we already have seen time travel was firstly rejected by both philosophy and science, as they tried to prove it was false on various grounds. In the last twenty years both tried to reconsider their positions regarding time travel. The discussions about the possibility of time travel were philosophically enriched with concepts involving human action, free will, Divine omniscience or personal identity and, above all, logic of possible worlds. Scientists believe that the would-be QFT will definitely clarify the problem of the actualisation of CTC in one of the two possible ways: either to provide the conditions in which they are possible, or to reject them as impossible at least at the stage before gravity itself is quantized. But if we are to accept this major challenge we have to reconsider most of our theories of time.

We want to investigate the compatibility between time travel and theories of time or at least some possible connections between them. There are some assumptions about time travel that come from theories of time, but it is not clear if time travel should be accepted they „would remain the same". We want to place the discussion on time travel in the context of temporal parts, continuants and occurrences and to prove that there are strong ontological commitments that cannot be neglected either by the

[47] [Horwich, 1987, 119].
[48] [Horwich, 1987, 123].

philosophers, or by the scientists. Theories of time are not unsympathetic to scientists as the occurrences-continuants distinction can be found in the important debate between the reality of particles (defended by K. Popper, A. Landé, etc.) and the reality of events in modern physics (defended by D. Bohm, J.-P. Vigier, E. Schrödinger and even A. Einstein). We will briefly present the two theories of time currently in debate among philosophers and logicians.

A) Four-dimensionalism[49] is based on a partial analogy between spatial and temporal parts. An object is spread in time much as it is spread out in space. The occupants of each span of time are different and each is a temporal part of the whole. The whole is a four dimensional object, more precisely a super-object with a spatiotemporal extension, a „worm".[50] So the four-dimensionalist says that my current temporal part is atemporally part of the larger space-time „worm" that is my body.

Zemach[51] defines four ontologies based on the difference between being continuos in a certain dimension (having no parts and undergoing change in this dimension as a *whole*) and being bound in a certain dimension (having parts along this dimension and parts having different attributes). The four-dimensionalism is an „ontology of events" that carves its entities as bound in time and space. These entities with boundaries in all four dimensions are events, or non-continuants, or processes. For a four-dimensionalist („first" in Zemach' classification) the classical three-dimensional object as continuant can be imagined as a „lazy process". Only events are real and only they can be predicated, can have proper names and only they are the substances of the world.[52] For a strong four-dimensionalist reality contains only processes.

This perspective adopts the atemporal parthood and atemporal exemplification. Change is only a difference between temporal parts. Saying that x has a property P at t means simply that x has a temporal part at t that has *atemporally* P or „the t-part of x has P". Temporal properties are carried *simpliciter* and they are not relative to time.

In the four-dimensionalism proposed by Sider we have attributes like „part of ... at t" instead of something atemporal, „part of", that is, a language with mereological concepts temporally qualified. Sider adopts a more relaxed four-dimensionalism. He does not suppose that facts about temporal parts are prior to or more fundamental than facts about continuants and that continuant objects are in any sense constructed from their temporal parts.[53] He doesn't assert a strong Humean Supervenience that local

[49] The terminology is used in [Van Inwagen, 1990] and recently in [Sider 1997], but we will use as well other designations as Temporal Part Theory (TPT) for four-dimensionalism and Continuant Theory (CT) for three-dimensionalism, as they are used in literature e.g. [Zemach, 1970], [Le Poidevin, 2000]. The doctrine of four-dimensionalism was firstly advocated by Russell *Our Knowledge of the External World*, 1914, A. N. Whitehead, *An Enquiry Concerning the Principles of Natural Knowledge*, 1918, R. Carnap, *Introduction to Symbolic Logic*, 1958 and W. v. O. Quine, *Word and Object*, 1960.

[50] R. Taylor describes the analogies between time and space in „Spatial and Temporal Analogies", in *Journal of Philosophy*, 52(22), 599-612. „Spatially long" is the same and „having a long duration", there are temporal places as spatial ones, there exists also temporal movement as spatial movement, etc. and answers to seven possible objections to these analogies. This paper was strongly criticised by J. Meiland, R. Gale, G. Schlesinger, J. Butterfield and T. Chapman on various grounds. We will discuss further Chapman's critique of analogies between spatial and temporal parts as it is significant to the time travel.

[51] [Zemach, 1970, 232-3].

[52] [Zemach, 1970, 234].

[53] [Sider, 1997, 208]. In an analysis of R. Taylor' analogies, Meiland shows that there are disanalogies between temporal parts and spatial parts, like „a spatial part is a set of temporal parts" and „a temporal part is not a set of spatial parts" [Meiland, 1966, 68] and concludes that „time is prior to space" [Meiland, 1966, 70]. Meiland advocates temporal parts without accepting all analogies found in Taylor. Schlesinger considers that a world without time and only with space would be totally stripped of the capacity of containing individuals, whereas a world devoid of space can sustain a system of particulars of a certain kind (*Aspects of Time*, 1980, p.18; the example of a temporal world without space is from Strawson's *Individuals*).

qualities would be instantiated by temporal parts and facts about temporal parts would determine all facts about identity over time. He says that temporal parts exist (as a consequence of the „Thesis of Temporal Locality").[54] He separates the problem of existence of temporal parts from the problem of their priority, reducibility etc.[55] Sider's argument in defence of four-dimensionalism, i.e. the Thesis of Temporal Locality (TTL), is parallel to Lewis's argument for the unrestricted mereological composition, according to which any class of objects whatsoever has a fusion.[56]

Four-dimensionalism confers great advantages in logic and especially mereology because it rescues extensional mereology. This model removes the temporal modification from predicates and builds it into terms. There is no need for tensed predicates or time indexicals. Four-dimensionalism reformulates ontology in another language, already familiar to us.[57] The new language is more consonant with STR, but as P. Simons suggests that „the rejection of the old ontology must be postponed until such time as the promised better alternative is in a more liveable state."[58]

We will put stress here on the analogy between spatial and temporal parts because the most influential philosophical paper about time travel in recent years is Davis Lewis' „The Paradoxes of Time Travel"[59] where he suggests a connection between temporal parts and time travel in a clear four-dimensionalist way. But the analogy was first hinted at by Richard Taylor. We will discuss it and after that the critique of Chapman.

For Taylor „spatially long" is the same as „having a long duration", there are temporal places as spatial ones, there exists also temporal movement as spatial movement, etc. He answers seven possible objections to these analogies (his paper was strongly criticised afterwards by J. Meiland, R. Gale, G. Schlesinger, J. Butterfield and T. Chapman on various grounds). In support of temporal parts theory he gives an answer to the following objection: „A thing can move back and forth in space, though it cannot do so in time".[60] Considering the example of a whistle blast moving in three different towns L1, L2 and L3 as follows:

	L_1	L_2	L_3
T_1	S_1	-	S_3
T_2	-	S_2	
T_1	S_2, S_3		

So we can admit that some spatial parts of an „object" can move backward in time. Chapman shows that we cannot imagine a time travel based only on analogy between time and space. He criticises Taylor's concept of movement in time. Movement back and forth in space is possible at different times. If space and time were analogous, we could find a state of affairs like the one depicted by Taylor, but there are many differences, largely commented upon in the philosophical literature. Chapman considers that Taylor replaces the object with a super-object which is the spatio-temporal path of the object in time and he cannot use the concept of travel in time neither about a travel in space, as his conceptual scheme drops the „absolutely fundamental notion of an object (in our sense) having a velocity".[61] For Taylor motion is a successive appearance of temporal bits of super-objects.

The spatial analogy doesn't help us very much in the discussion about time travel because identity (and reidentification) in time is different from identity in space. Belonging to a temporal part is different to belonging to a spatial part. Otherwise, it is clear enough that the analogy between spatial and temporal part can be refuted without damaging the theoretical basis of four-dimensionalism. This analogy itself is too weak to stay as the sole ground for this doctrine.

B) Three-dimensionalism defends a contrary position, the one we use most and that comes almost naturally to us. Things persist through time and they are wholly present throughout time. The entire object is to be found at each instant of time. There is a great disanalogy between occupying time and occupying space: spatial part can exhibit incompatible properties, it doesn't imply change as we have different particulars in different places. An object may have completely different properties and this doesn't mean it is contradictory. Temporal variations may imply change of one and the same individual who persists through change.

The strong slogan of three-dimensionalism is: for every x and every t at which x exists, every part of x exists at t. Sider change it slightly: „x is wholly present at t if everything that is at any time part of x exists and is part of x at t".[62] He presents some possible theses of three-dimensionalism, but finally the single thesis acceptable for all three-dimensionalists is the weaker one: „It is possible that some object is wholly present at more than one time".[63] Parthood is irreducibly temporally relative and properties are relative to time.

There are also other ways to state this doctrine. We can express it as follows: objects are „continuants"[64] and „the collection is not a plurality, but a specific kind of unity", they have no temporal parts. Things are bound in space and continuous in time, if we adopt Zemach's classification: this constitutes the second ontology, „ontology of things". An object can be sliced in space, it has spatial boundaries. In respect of time, a continuant is not „defined", it has no boundaries. David Lewis opposes „perduring" to „enduring": something „*perdures* iff it persists by having different temporal parts or stages".[65] Occurrents (in C.D. Broad terminology, or „events", „non-continuants") are very intimately related to time, but in general they are not clearly located in space; continuants have a direct relation to space and an indirect one to time.

The mereology of temporary parts of continuants adds a temporal qualified relation of „being part of … at *t*" alongside the timeless logical notion of „being part of" $<_t$ and a temporal predicate of existence, temporally modifiable, $Ex_t a$. This temporal mereology permits us to convey many classical theorems of mereology in the language of temporary parts. We can redefine all the concepts from calculus of

54 *Thesis of Temporal Locality* in a atemporal form: „Necessarily, for any object, x, and for any non-empty non-overlapping sets of times T_1 and T_2 whose union is the time span of x, there are two objects x_1 and x_2 such that (i) x is the fusion of x_1 and x_2 and (ii) the time span $x_1 = T_1$, whereas the time span of $x_2 = T_2$". The atemporal definition of „temporal part" is: „x is an instantaneous temporal part of y at instant t $=_{df}$ (i) x is a part of y, (ii) x exists at, but only at t, and (iii) x overlaps every part of y that exists at t." [Sider, 1997, 206].

55 [Sider, 1997, 208].

56 [Sider, 1997, 214] and [Lewis 1986b, 212-213]. The strong claim proved to support TTL is: „every assignment has a minimal diachronic fusion".

57 [Simons, 1987, 123].

58 [Simons, 1987, 127].

59 Published first in *American Philosophical Quarterly*, 13 (1976).

60 [Taylor, 1955, 610].

61 [Chapman, 1982, 137].

62 [Sider, 1997, 210].

63 Other thesis of three-dimensionalism are: „necessarily, there are no temporal parts", „necessarily, nothing that exists for more than an instant ever has a temporal part", „necessarily, in the actual world small particles are wholly present throughout their lifetimes", etc. All these thesis are by necessity. In Sider's view, there are too strong for all three-dimensionalists [Sider, 1997, 210-211].

64 W. E. Johnson used for the first time the term of „continuant". *Logic*, vol. I, CUP, 1921, p. 200.

65 [Lewis, 1986b, 202].

individuals developed by Lesniewski (1916) and Leonard and Goodman (1942) in the theory of continuants with time: proper part ($a <<_t b$), overlapping ($a\ o_t\ b$), binary product, binary sum, etc. Disjointness can be interpreted in at least three modes, but we haven't to enter in details here.[66] Much more important is the definition of mereological constancy and variability (MC and MV):

$$MCa \equiv \forall tt'(Ex_t\ a \wedge Ex_{t'}\ a \supset \forall x\ (x <_t a \equiv x <_{t'} a)) \text{ and } MV\ a \equiv \sim MC\ a$$

which says that an object is mereological constant between two instants if all its parts that exist at the two instants are identical.

These two theories of time have proponents and disputants. David Lewis rejects the three dimensionalism and the view of enduring objects. An object *endures* „iff it persists by being wholly present at more than one time". Things endure and they are timelike streaks. Each object is composed of temporal parts or stages. Change is solely a difference between temporal parts as are the differences between spatial parts of an object. Objects can't change if they have no temporal parts.[67] In another terminology, „occurrent" objects are opposed to „continuant" objects as they have temporal parts and they endure. „Continuants" have characteristically spatial parts but as well temporal parts and they perdure.[68] Traditionally events are considered as occurrents and things as continuants. Metaphysicians accept either in a reductionist, or in a eliminativist manner one of the three alternatives: 1) the world is completely constituted of continuants, 2) the world is completely constituted of occurrents, or 3) the world is composed of continuants and occurrents.

Four-dimensionalism can be rejected from a three-dimensionalist point of view on the basis of next objections: a) parts must be causally identifiable independently of the wholes they are part of; b) if objects have a temporal parts, then an object existing at one time cannot literally be identical with an object existing at another; c) temporal parts presuppose already an ontology, unlike spatial parts; d) if we accept that objects have temporal parts, the difference between objects and events would collapse; e) on a temporal parts ontology (e.g. Quine's) nothing genuinely changes.[69] It can be noticed that b), c) and d) can be rejected on various grounds and in general a) and e) are much more stimulating for philosophical discussions. There are other arguments against temporal parts like the logic impossibility of instantaneous parts, „ex nihilo" existences, time-space analogies and Humean causes.[70] We can also reject four dimensionalism on the basis of a disanalogy between spatial and temporal parts. For example, Butterfield's conclusion is that detensers don't need temporal parts and we can continue to use our three-dimension intuitions about parts without any danger.[71] Van Inwagen rejects temporal part theory on a basis like the paradox of composition of classes, showing that temporal parts are „modally inductile" (the temporal extents of a temporal part must belong to their essence) and also the super-object as a whole must be modally inductile, which is false.[72] But in this paper we are not here generally concerned with arguments against four-dimensionalism.

In our language we accept a combination between four-dimensionalism and three-dimensionalism. Normally we use temporal parts language only for occurrents and a

66 See for details [Simons, 1987, 179-181].
67 [Lewis, 1986a, 68].
68 [Simons, 2000].
69 [Le Poidevin, 1991, 59-60].
70 [Bordes, 1997, 343].
71 [Butterfield, 1985, 41].
72 [Van Inwagen, 1990, 253].

continuants language for describing continuants. The two doctrines can coexist without problems, as we are using the same language with objects and events as referents.[73] By our intuition we can accept that continuants are parts of occurents and also we admit that even if the members of a class are continuants, the class can be an occurrent.[74] We can accept that objects have temporal parts as well as spatial parts, but it depends on the ontological structure of that object. Spatial parts can be divided without problem into spatial subcomponents, and also into temporal components, too. But some objects and events have spatial and temporal parts as well. Without accepting vagueness we can say that the division is dependent of the ontological complexity of the object or events. World War II had temporal parts as well as spatial parts. We can also speak without problem of a spatial part of a temporal part (the Stalingrad battle of the 1943 winter campaign of the Wehrmacht in Russia), as well as a temporal part of a spatial part („Galerie des Glaces" from Palace of Versailles in 1919). Theoretically the recursion has no limit, we accept second order non-homogenous relation of parthood, e.g. spatial part of a temporal part of a spatial part (and all other combinations).[75]

7) Testing theories of time with time travel

Time travel cannot be refuted only by proving that space and time are different. It cannot be rejected only on the anthropomorphic claim that it is counter-intuitive and infringes our outlook of a easily-comprehensible and easily-governed world. As we already noticed, classical GTR seems incapable to reject it internally and we are not sure that QFT will help us very much. It is true that time travellers do not invade us as space travellers do, but this is available only for a „reasonable" range of periods of time that can be measured and kept under surveillance. Nobody knows if at a small or at a large time-scale CTC constitutes a possible, or much more, a necessary feature of the world. Recently physicists have conjectured that singularities and black holes should be almost everywhere, even in our body, but we haven't yet detected them. If time travel is rejected the endeavour of science and philosophy to comprehend the world should be made easier, the world should be more dull and domestic, but we risk committing a great fallacy of ignorance. Neither can logic help very much, as the principles and axioms of classical system of logic cannot be used to reject time travel. The simplest reason is that the temporal logic we normally use is inspired from natural language and they are based on the isomorphism between order of temporal entities and order of real or rational numbers.

The analogy between space and time as well as the isomorphism of time scale with the real number set are topological questions. The ontological difference between objects in time cannot be reduced to or deduced from the ontological difference between objects in space. Perceivability and measurability of CTC are questions regarding our capacity to measure changes over small or large periods of times, the constancy of physical laws and constants of physics, history of Universe, etc. It is not very clear if our clocks and chronometers are not *a priori* conceived to elude close times. It is not very clear if we can produce CTC or just use an already existing one. We haven't them yet at hand, but we cannot conceive them or describe them mathematically or even simulate them on computers. Global properties of „Time"

73 See David Wiggins in *Sameness and Substance*, Blackwell, 1980 and [Simons, 1987, 130].
74 [Simons, 1987, 176].
75 Although Meiland rejects the thesis that „*in general* a temporal part is a set of spatial part" [Meiland, 1966, 68].

cannot be inferred from local observations of properties of small periods of times. If CTC, branching or cyclic time, multidimensional time or forking past are not common in everyday experience, we cannot infer that they are logically impossible and we cannot carve „Time" in general.[76]

Time travel is crying out for a stronger ontological version, regarding the reality of temporal objects, more exactly the theories involving the reality of objects in time. We will try now to investigate the possibility to adapt the theories of time to time travel. If we want to improve their power of expression possibly we have to amend them. Theories of time in a simplistic form cannot accept time travel completely. It seems that time travel is partially compatible with both theories of time but it has many conflicting points. Two remarks are necessary to emphasise this strange „outlaw" feature of time travel for both three-dimensionalism and four-dimensionalism.

The first remark concerns the relation of a time traveller to the reality of temporal objects. The destination of a time traveller is the realm of past objects. How real can be a past object and a future one? This concerns the ontological aspect of the tense/tenseless debate. We are not entering here into details but it is worth noting that beyond the debate about the truth conditions of tense propositions, there is an ontological problem of reality of things existing in time. Presenteism says that only present things are real. David Lewis rejects presenteism on the basis of an analogy between space and time. He asserts that rejecting the reality of past and future is as hidebound as denying the reality of distant places. The spatial analogy is unimportant here and can drive us into confusion. We cannot accept presenteism together with time travel because if something acts upon something it has to be as real as the second (the problem of impotence of future entities). Time travel seems also incompatible with the idea of the objective flow of time based on the branching model advocated by Storrs McCall.[77]

A Parmenidian outlook in which past, present and future are equally real can make sense of time travel, while presenteism is at odds with the possibility of time travel.[78] But it would be better to accept degrees of existence (or reality) in time. The Scholastic view of „degrees of being" can be adapted to the temporal existence. Past objects exist in a weaker sense than present things and in a stronger sense than future things. This chain of being can be defined by the relation of causality or „power to act upon". The reality of some past and future objects can be differentiated and can be distinguished by the power of acting one upon other. In some sense this hypothesis can resolve the grandfather paradox.

Secondly the time machine and its occupant are objects in a full sense, which means that they are *continuants*. That happens in grandfather and autoinfanticide paradoxes when the traveller is trying to kill his grandfather or his younger ego. In doing so he is acting like a substance wholly present at each stage. This example is preferred and it is a very shocking one because it involves personal identity, agent and

[76] However in computer science and artificial intelligence branching time model, multidimensional time and forked past are commonly used and mathematical models are provided (see Dov M. Gabbay, Ian Hodkinson, and Mark Reynolds (eds.) *Temporal logic: mathematical foundations and computational aspects,* Oxford University Press, vol. 1-2, 1994-2000). We don't know yet about an *analogon* of CTC in temporal logic, but it should be correlated with systems with strong feed-backs and auto-correction. Otherwise a system evolving on a closed time „loop" should gain instantly information about itself. Volume 3 of this series will eventually provide a discussion on time travel logic.

[77] *A Model of the Universe: Space-Time, Probability, and Decision*, Oxford University Press, 1994.

[78] [Grey, 1999, 56].

free will. As Hume mentioned, we dislike the temporal part theory because we think of ourselves as continuants, having a personal identity through time and being wholly present during our lives.[79] Classical discussion of time travel doesn't give up the continuant theory either in this case. Time traveller is a person and remains a person during his journey in the past, so he is a special kind of substance, i.e. a continuant. Even Feynman's interpretation of positrons as electrons travelling backward in time and the hypothesis of tachyons as making communication to the past possible are reliant on a theory of objects as continuants. Tachyons are particles and they can carry energy and information, so they have attributes and can be defined in an essentialist way. The examples of laser beams or radio waves carrying information and travelling backward in time are less discussed. That means that in the time travel „drama" continuants are more important than occurrents. But continuants are the source of paradoxes in time travel because their existence as objects at a future time can be jeopardised by their own existence in the past. We have two solutions: either to change the time traveller to a wave or to an object less real then a wave or other form of information carrier, or to consider that the existence of a time traveller can be described neither as a continuant, nor as an occurrent.

It seems that time travel as a succession of occurrents will raise less problems than if we allow continuants to travel in time. We can have simultaneously access to different parts of an occurrent, whereas we cannot different temporary parts of a continuant. Think of a concert that can be listened to directly or can be delayed acoustically in time by a special medium. We have access to two distinct part of the same occurrent. Different temporal parts of the same occurrent can overlap. If we hear a concert delayed in time and the concert itself we accept them as equally real. We notice naturally that there is a difference between the entanglement of meeting a younger ego and the experience of hearing simultaneously a concert and its former replica, only delayed in time. If a wave is sufficiently coherent it can annihilate itself in a region of space or time by interference. The auto-annihilation of a wave in time doesn't intrigue us or at least it disturbs us less than auto-infanticide. But what about the delay in time? We can delay occurrents in time but cannot delay continuants in time. To record the moving image of a person means to access information about a temporal part of him and this record is less real than the continuant itself because it is ontologically dependent on it: an object in time can be delayed in time only as image and by this process the original reality of the object is lost. We cannot accept that two different temporal parts of an object could stand in almost the same space and have the same degree of reality. One of them have to be less real. It is clear that a time journey is itself an occurrent, as it has temporal parts, it is a process and it has phases. A clear four-dimensionalist tendency affects the scientific description of time travel. The CTC are worldlines with temporal parts. It is also very important to remark that the general case is CTC and from it can be derived the evolution on an ordinary timelike curve as a limit case.

Thirdly there is an important connection between possible world semantics and time travel which has not been enough discussed. It is clear that a time traveller coming from $w_1(t_1)$ who can change the past, i.e he is travelling to the world $w_0(t_0)$ and acts upon it, will force the universe to follow another path and to reach another

[79] *A Treatise on Human Nature*, I, IV, II.

future possible world $w_3(t_1)$ and w_1 and w_3 can be mutually incompatible. But this approach is a strong realistic one and it can be rejected on various grounds.#[80]

In the first sections of this paper it was revealed how time travel occupies a strange place in our outlook of the world, being atypical for both scientific and philosophical thought. In the last section we brought to light some difficulties encountered by the two theories of time to capture fully the reality of time travel. There is a strong tendency of naturalisation in philosophy today. It is clear that a time traveller is not as simple as a spatial one and to visit your younger ego cannot be like a journey to an old aunt in the countryside. If occurrents and continuants can coexist and can be caught in ordinary language and ordinary thought, an object going through a CTC is not simply an occurrent or a continuant. It is possible that we have to leave place for this third type of temporal object, something that isn't yet present in our language and cannot be accommodated with our minds. The presence of a time traveller can be considered as a third type of existence: he is in a real world but he can influence no objects in it that are temporal parts of the whole to which he belongs. It remind us of the difference between quantum particles and macroscopic objects or the difference between wave and corpuscle. It is better to accept it as a new type of temporal existence and not to force it into our classical view of occurrent and continuants.

Ioan-Lucian Muntean[*]

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* Faculty of Philosophy, University of Bucharest, Romania, e-mail: *muntean@fil.unibuc.ro* This paper is the result of a research scholarship of Romanian Ministry of Education as a visiting scholar at the University of Leeds. I am very grateful to Katherine Brading, Jeremy Butterfield, John Divers, Robin Le Poidevin, Joseph Melia, Peter Morgan, William Newton-Smith, Scott Shalkowski and Peter Simons for criticisms which have helped to shape the paper.

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